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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

# WARTIME REPORT

ORIGINALLY ISSUED
April 1945 as
Memorandum Report E5D04

## KNOCK-LIMITED PERFORMANCE OF SIX AROMATIC AMINES BLENDED WITH A BASE FUEL IN A FULL-SCALE AIRCRAFT-ENGINE CYLINDER

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WASHINGTON

NACA MR No. E5D04

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

# KNOCK-LIMITED PERFORMANCE OF SIX AROMATIC AMINES BLENDED WITH A BASE FUEL IN A FULL-SCALE AIRCRAFT-ENGINE CYLINDER

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## SUMMARY

Tests were made to investigate the effect of 2-percent additions of six aromatic amines on the knock-limited performance of 28-R fuel in a full-scale aircraft-engine cylinder. Tests were conducted with a Wright R-1820 G200 cylinder at two operating conditions with a 2-percent blend in 28-R fuel of the following six aromatic amines: N-methylxylidines (mixed isomers), N-methylcumidines (mixed isomers), N-methyltoluidines (75 percent p-, 25 percent o-), xylidines (mixed isomers), cumidines (mixed isomers from refinery cumene), and N-methylaniline (pure). Correlations of the full-scale engine data with published small-scale engine data are also presented.

The results are summarized in the following table:

RATINGS OBTAINED IN A WRIGHT R-1820 G200 CYLINDER

[For each compound there are two rows of values. The first row is imep, lb/sq in.; the second is imep ratio, which is the ratio of the imep of 98 percent 28-R fuel plus 2 percent aromatic amine to the imep of 28-R.]

| Compound | Concentration in 28-R fuel[a] (percent by wt.) | Engine speed, 2000 rpm; inlet-air temperature, 210° F | | | |
|---|---|---|---|---|---|
| | | Spark advance, 20° B.T.C.; atmospheric exhaust pressure | | Spark advance, 30° B.T.C.; exhaust pressure, 15 in. Hg absolute | |
| | | Fuel-air ratio | | Fuel-air ratio | |
| | | 0.07 | 0.10 | 0.07 | 0.10 |
| N-methylxylidines (mixed isomers) | 2 | 193<br>1.25 | 283<br>1.12 | 184<br>1.03 | 249<br>1.06 |
| N-methylcumidines (mixed isomers) | 2 | 208<br>1.34 | 290<br>1.15 | 194<br>1.08 | 259<br>1.10 |
| N-methyltoluidines (75 percent p-, 25 percent o-) | 2 | 216<br>1.39 | 288<br>1.14 | 187<br>1.05 | 260<br>1.10 |
| Xylidines (mixed isomers) | 2 | 192<br>1.24 | 280<br>1.11 | 184<br>1.03 | 257<br>1.09 |
| Cumidines (mixed isomers from refinery cumene) | 2 | 200<br>1.29 | 282<br>1.11 | 188<br>1.05 | 250<br>1.06 |
| N-methylaniline (pure) | 2 | 210<br>1.36 | 290<br>1.15 | 190<br>1.06 | 262<br>1.11 |
| Base fuel (28-R) | 100 | 155<br>1.00 | 253<br>1.00 | 179<br>1.00 | 236<br>1.00 |

[a]Final tetraethyl-lead content in blends, 4.44 ml/gal.

## INTRODUCTION

A general investigation to determine the effectiveness of aromatic amines as antiknock additives for aviation fuels is being conducted at the Cleveland laboratory of the NACA at the request of the Army Air Forces, Air Technical Service Command. Two-percent blends of approximately 45 aromatic amines in 28-R fuel have been tested with an F-3 and an F-4 engine and the results are reported in references 1 to 4. The results of these tests, the physical properties of the amines (references 5 to 7), and the feasibility of their preparation were the deciding factors in the selection of six aromatic amines for tests in a full-scale aircraft-engine cylinder.

The present report gives the results of knock tests, conducted between November 1944 and February 1945, using 2 percent of each of the six aromatic amines blended with 28-R fuel at two operating conditions in a Wright R-1820 G200 cylinder. The full-scale engine data are correlated with CFR engine data taken from references 2 to 4.

## FUELS

The Organic Synthesis Section of the Fuels and Lubricants Division prepared approximately 10 pounds of each of the following unleaded aromatic amine fuels:

N-methylxylidines (mixed isomers)
N-methylcumidines (mixed isomers)
N-methyltoluidines (75 percent p-, 25 percent o-)
Xylidines (mixed isomers)
Cumidines (mixed isomers from refinery cumene)
N-methylaniline (pure)

The aromatic amine fuels were mixed with 28-R, which is a grade 100/130 fuel, to form blends of 2 percent aromatic amine and 98 percent base fuel by weight. Because the base fuel contains 4.53 ml TEL per gallon, the tetraethyl-lead concentration of the final aromatic amine blend was 4.44 milliliters per gallon.

## APPARATUS AND TEST PROCEDURE

Apparatus. - The tests were conducted with a Wright R-1820 G200 cylinder mounted on a CUE crankcase. The auxiliary apparatus used in these tests was similar to that described in reference 8 except that a heat exchanger was installed in the cooling-air line to control the cooling-air temperature and the exhaust system was so modified that the engine could be operated either at atmospheric pressure or at a reduced exhaust pressure.

Test conditions. - The fixed engine conditions were:

| | |
|---|---|
| Engine speed, rpm | 2000 |
| Inlet-air temperature, °F | 210 |
| Compression ratio | 7.3 |
| Oil flow to piston jets, pounds per minute | 8 |
| Oil-in temperature, °F | 180 to 185 |
| Fuel temperature at entrance to injection pump, °F | 60 to 80 |
| Cooling-air temperature, °F | 85 ±3 |
| Spark advance, degrees B.T.C. (both plugs) | 20 and 30 |
| Exhaust pressure, inches of mercury absolute | 29 ±0.5 and 15 |
| Valve timing: | |
| Intake opens, degrees B.T.C. | 15 |
| Intake closes, degrees A.B.C. | 44 |
| Exhaust opens, degrees B.B.C. | 74 |
| Exhaust closes, degrees A.T.C. | 25 |

The cooling-air flow was determined for each test by operating the engine at a brake mean effective pressure of 140 pounds per square inch and a fuel-air ratio of 0.10 and by adjusting the damper valve in the cooling-air line until a rear spark-plug-bushing temperature of 365° F was reached. The cooling-air pressure drop across the cylinder thus determined was maintained constant for each test.

The mixture-response curves were determined at two operating conditions: (a) simulated cruise conditions recommended by the Coordinating Research Council, which specify an engine speed of 2000 rpm, an inlet-air temperature of 210° F, a spark advance of 20° B.T.C., and atmospheric exhaust pressure; and (b) a modification of these CRC conditions that consisted in an advance spark setting of 30° B.T.C. and a reduced exhaust pressure of 15 inches of mercury absolute. The exhaust pressure of 15 inches of mercury was chosen in view of test results reported in reference 9, in which a critical relation was shown to exist between manifold and exhaust pressures and knock-limited power in the lean region where the manifold pressure is within +10 or -5 inches mercury of the exhaust pressure. The spark advance of 30° B.T.C. was chosen because of the interest in aircraft-engine operation at advanced spark under cruising conditions.

of their preparation were the deciding factors in the selection of six aromatic amines for tests in a full-scale aircraft-engine cylinder.

The present report gives the results of knock tests, conducted between November 1944 and February 1945, using 2 percent of each of the six aromatic amines blended with 28-R fuel at two operating conditions in a Wright R-1820 G200 cylinder. The full-scale engine data are correlated with CFR engine data taken from references 2 to 4.

## FUELS

The Organic Synthesis Section of the Fuels and Lubricants Division prepared approximately 10 pounds of each of the following unleaded aromatic amine fuels:

N-methylxylidines (mixed isomers)
N-methylcumidines (mixed isomers)
N-methyltoluidines (75 percent p-, 25 percent o-)
Xylidines (mixed isomers)
Cumidines (mixed isomers from refinery cumene)
N-methylaniline (pure)

The aromatic amine fuels were mixed with 28-R, which is a grade 100/130 fuel, to form blends of 2 percent aromatic amine and 98 percent base fuel by weight. Because the base fuel contains 4.53 ml TEL per gallon, the tetraethyl-lead concentration of the final aromatic amine blend was 4.44 milliliters per gallon.

## APPARATUS AND TEST PROCEDURE

Apparatus. - The tests were conducted with a Wright R-1820 G200 cylinder mounted on a CUE crankcase. The auxiliary apparatus used in these tests was similar to that described in reference 8 except that a heat exchanger was installed in the cooling-air line to control the cooling-air temperature and the exhaust system was so modified that the engine could be operated either at atmospheric pressure or at a reduced exhaust pressure.

The F-3 ratings of three of the aromatic amine fuel blends are presented in the following table, which indicates that the blend of cumidines gave the best performance when compared with N-methylcumidines and N-methylxylidines.

F-3 RATINGS OF 2-PERCENT BLENDS OF AROMATIC AMINES AND 28-R FUEL

| Compound | Concentration in 28-R fuel[a] (percent by wt.) | F-3 ratings | |
|---|---|---|---|
| | | S-3 + ml TEL | Performance number |
| 28-R | 100 | 0 | 100 |
| N-methylxylidines[b] | 2 | .06 | 102 |
| N-methylcumidines[b] | 2 | .04 | 102 |
| Cumidines[c] | 2 | .13 | 105 |

[a]Final tetraethyl-lead content in blends, 4.44 ml/gal.
[b]Data from reference 4.
[c]Data from reference 3.

Correlation of Full-Scale and Small-Scale Engine Results

The correlation of the Wright R-1820 G200 cylinder data with the CFR engine data from references 2 to 4 is presented in figures 3, 4, and 5. The data in figure 3 indicate that at a fuel-air ratio of 0.07 the Wright R-1820 G200 cylinder at both operating conditions gives a higher rating to the aromatic amine blends than the F-4 engine. At a fuel-air ratio of 0.10 the F-4 data agree favorably with the R-1820 G200 data at modified CRC cruise conditions.

The correlation between the Wright R-1820 G200 cylinder data and the CFR modification A (fig. 4) is better than that with the F-4 ratings in the lean region. The agreement is good in the rich region, especially for the R-1820 G200 cylinder at CRC cruise conditions. The correlation between the data for the R-1820 G200 cylinder and the data for the CFR modification B (fig. 5) is also better than that with the F-4 engine in the lean region. In the rich region the agreement is better at the specified CRC cruise conditions than at the modified cruise conditions.

This investigation indicates that an F-4 engine run at the CFR modification A conditions gives results which more closely approximate those obtained in a full-scale aircraft-engine cylinder than either of the other two small-scale methods studied.

## SUMMARY OF RESULTS

From tests to determine the antiknock effectiveness of 2-percent additions of six aromatic amines to 28-R fuel at two operating conditions in a Wright R-1820 G200 cylinder, the following results were obtained:

1. All the six aromatic amine blends increased the knock-limited power of the base fuel at both operating conditions throughout the fuel-air-ratio range.

2. At a fuel-air ratio of 0.065, the greatest increases in the knock-limited performance of the base fuel were observed with the blends of N-methyltoluidines, N-methylcumidines, and N-methylaniline at the CRC cruise conditions, and with the blends of N-methylcumidines and N-methylaniline at the modified cruise conditions.

3. At a fuel-air ratio of 0.10, N-methylcumidines, N-methyltoluidines, and N-methylaniline gave approximately the same knock-limited performance; the increase over the base fuel was greater at the CRC cruise conditions than at the modified cruise conditions.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, April 4, 1945.

## REFERENCES

1. Branstetter, J. Robert: Knock-Limited Performance of Blends of AN-F-28 Fuel Containing 2 Percent Aromatic Amines - I. NACA Memo. rep., April 17, 1944.

2. Alquist, Henry E., and Tower, Leonard K.: Knock-Limited Performance of Blends of AN-F-28 Fuel Containing 2 Percent Aromatic Amines - II. NACA Memo. rep., June 26, 1944.

3. Alquist, Henry E., and Tower, Leonard K.: Knock-Limited Performance of Blends of AN-F-28 Fuel Containing 2 Percent Aromatic Amines III. NACA Memo. rep., Aug. 23, 1944.

4. Alquist, Henry E., and Tower, Leonard K.: Knock-Limited Performance of Blends of AN-F-28 Fuel Containing 2 Percent Aromatic Amines - IV. NACA MR No. E4L21, Dec. 21, 1944.

5. Olson, Walter T., and Kelly, Richard L.: The Low-Temperature Solubility of Aniline, Toluidines, and Some of Their N-Alkyl Derivatives in Aviation Gasoline. NACA Memo. rep., June 5, 1944.

6. Olson, Walter T., Tischler, Adelbert O., and Goodman, Irving A.: Gasoline-Water Distribution Coefficients of 27 Aromatic Amines. NACA Memo. rep., Aug. 3, 1944.

7. Kelly, Richard L.: The Low-Temperature Solubility of 24 Aromatic Amines in Aviation Gasoline. NACA MR No. E4K17, Nov. 17, 1944.

8. Jones, Anthony W., and Bull, Arthur W.: Knock-Limited Performance of Pure Hydrocarbons Blended with a Base Fuel in a Full-Scale Aircraft-Engine Cylinder. I - Eight Paraffins, Two Olefins. NACA ARR No. E4E25, 1944.

9. Cook, Harvey A., Held, Louis F., and Pritchard, Ernest I.: The Influence of Exhaust Pressure on Knock-Limited Performance. NACA MR No. E5A05, Army Air Forces, Jan. 5, 1945.

TABLE I - COMPARISON OF RATINGS OBTAINED IN A WRIGHT R-1820 G200 CYLINDER WITH CFR ENGINE RATINGS

[For each compound there are two rows of values. The first row is imep, lb/sq in.; the second is imep ratio, which is the ratio of the imep of 98 percent 28-R fuel plus 2 percent aromatic amine to the imep of 28-R.]

| Compound | Concentration in 28-R fuel[a] (percent by wt.) | CFR engine ratings | | | | | | Wright R-1820 G200 ratings (Engine speed, 2000 rpm; inlet-air temperature, 210° F; compression ratio, 7.3) | | | | | | | | | | Boiling point of amine (°F) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | F-4 (inlet-air temperature, 225° F; spark advance, 45° B.T.C.) | | Modification A (inlet-air temperature, 250° F; spark advance, 30° B.T.C.) | | Modification B (inlet-air temperature, 150° F; spark advance, 30° B.T.C.) | | Spark advance, 20° B.T.C.; exhaust pressure, 29 ±0.5 in. Hg absolute | | | | | Spark advance, 30° B.T.C. exhaust pressure, 15 in. Hg absolute | | | | | |
| | | Fuel-air ratio | | Fuel-air ratio | | Fuel-air ratio | | Fuel-air ratio | | | | | Fuel-air ratio | | | | | |
| | | 0.07 | 0.10 | 0.07 | 0.10 | 0.07 | 0.10 | 0.065 | 0.07 | 0.08 | 0.09 | 0.10 | 0.065 | 0.07 | 0.08 | 0.09 | 0.10 | |
| N-methylxylidines (mixed isomers) | 2 | ------ | ------- | ------ | ------- | ------ | ------- | 164 | 193 | 222 | 256 | 283 | 173 | 184 | 209 | 232 | 249 | 426 - 446 |
| | | [b]1.03 | [b]1.05 | [b]1.05 | [b]1.10 | [b]1.13 | [b]1.10 | 1.16 | 1.25 | 1.06 | 1.09 | 1.12 | 1.04 | 1.03 | 1.03 | 1.03 | 1.06 | |
| N-methylcumidines (mixed isomers) | 2 | ------ | ------- | ------ | ------- | ------ | ------- | 195 | 208 | 245 | 272 | 290 | 182 | 194 | 220 | 245 | 259 | 450 - 468 |
| | | [b]0.98 | [b]1.11 | [b]1.11 | [b]1.17 | [b]1.16 | [b]1.14 | 1.38 | 1.34 | 1.17 | 1.16 | 1.15 | 1.10 | 1.08 | 1.08 | 1.08 | 1.10 | |
| N-methyltoluidines (75% p-, 25% o-) | 2 | ------ | ------- | ------ | ------- | ------ | ------- | 195 | 216 | 244 | 275 | 288 | 178 | 187 | 204 | 239 | 260 | 405 - 415 |
| | | ------ | ------- | ------ | ------- | ------ | ------- | 1.38 | 1.39 | 1.17 | 1.17 | 1.14 | 1.07 | 1.05 | 1.01 | 1.06 | 1.10 | |
| Xylidines (mixed isomers) | 2 | ------ | ------- | ------ | ------- | ------ | ------- | 172 | 192 | 230 | 257 | 280 | 173 | 184 | 214 | 237 | 257 | 416 - 429 |
| | | ------ | ------- | ------ | ------- | ------ | ------- | 1.22 | 1.24 | 1.10 | 1.09 | 1.11 | 1.04 | 1.03 | 1.05 | 1.05 | 1.09 | |
| Cumidines (from refinery cumene - mixed isomers) | 2 | ------ | ------- | ------ | ------- | ------ | ------- | 184 | 200 | 237 | 257 | 282 | 173 | 188 | 215 | 232 | 250 | 428 - 442 |
| | | [c]1.02 | [c]1.04 | [c]1.10 | [c]1.07 | [c]1.09 | [c]1.11 | 1.30 | 1.29 | 1.13 | 1.09 | 1.11 | 1.04 | 1.05 | 1.06 | 1.03 | 1.06 | |
| N-methylaniline | 2 | ------ | ------- | ------ | ------- | ------ | ------- | 192 | 210 | 240 | 269 | 290 | 181 | 190 | 218 | 240 | 262 | 381 - 385 |
| | | [d]0.99 | [d]1.10 | [d]1.15 | [d]1.13 | [d]1.13 | [d]1.11 | 1.36 | 1.36 | 1.15 | 1.14 | 1.15 | 1.09 | 1.06 | 1.07 | 1.06 | 1.11 | |
| Base fuel (28-R) | 100 | ------ | ------- | ------ | ------- | ------ | ------- | 141 | 155 | 209 | 235 | 253 | 166 | 179 | 203 | 226 | 236 | -------- |
| | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | |

[a]Final tetraethyl-lead content in blends, 4.44 ml/gal.

[b]Data from reference 4.

[c]Data from reference 3.

[d]Data from reference 2.

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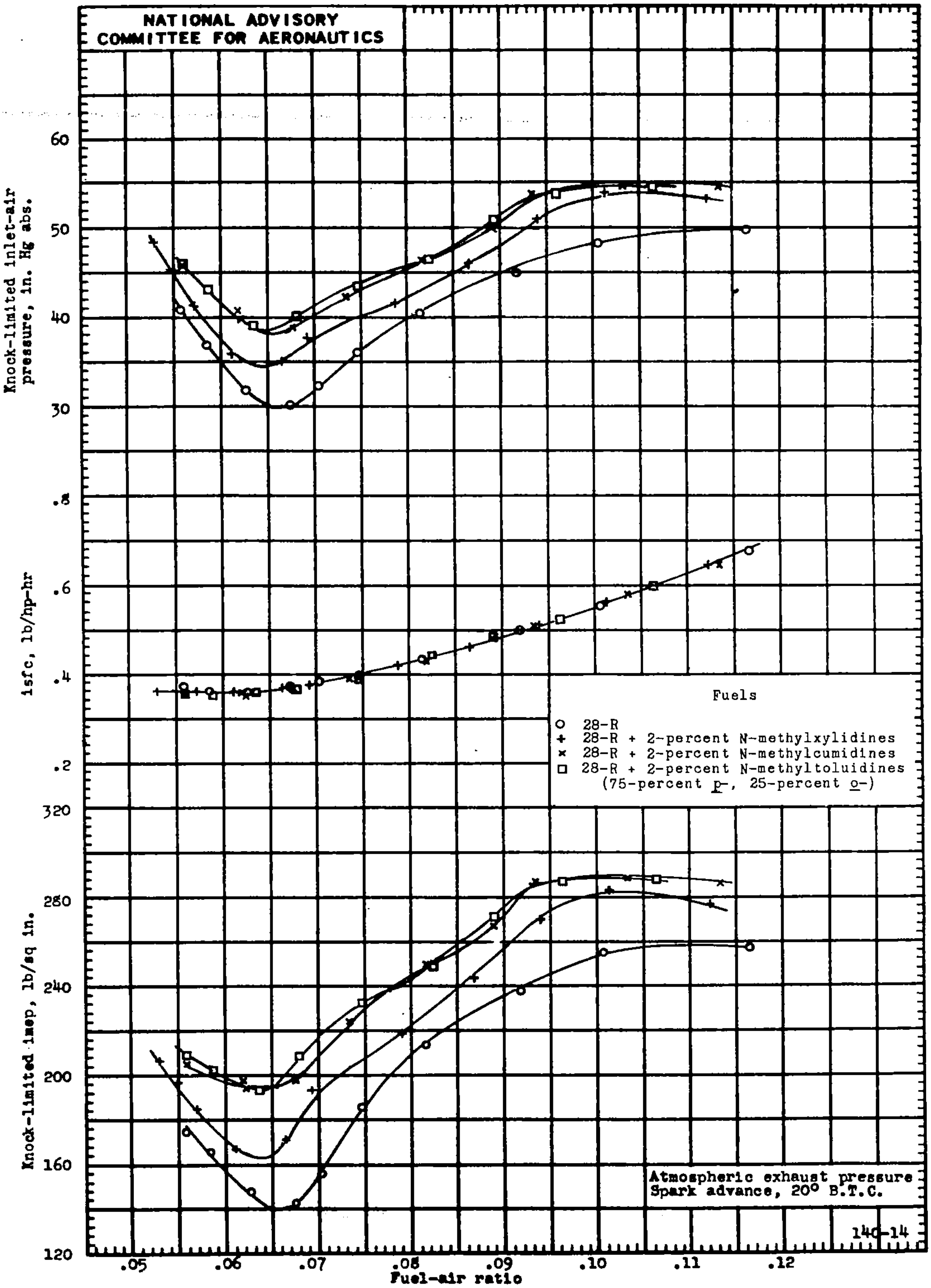
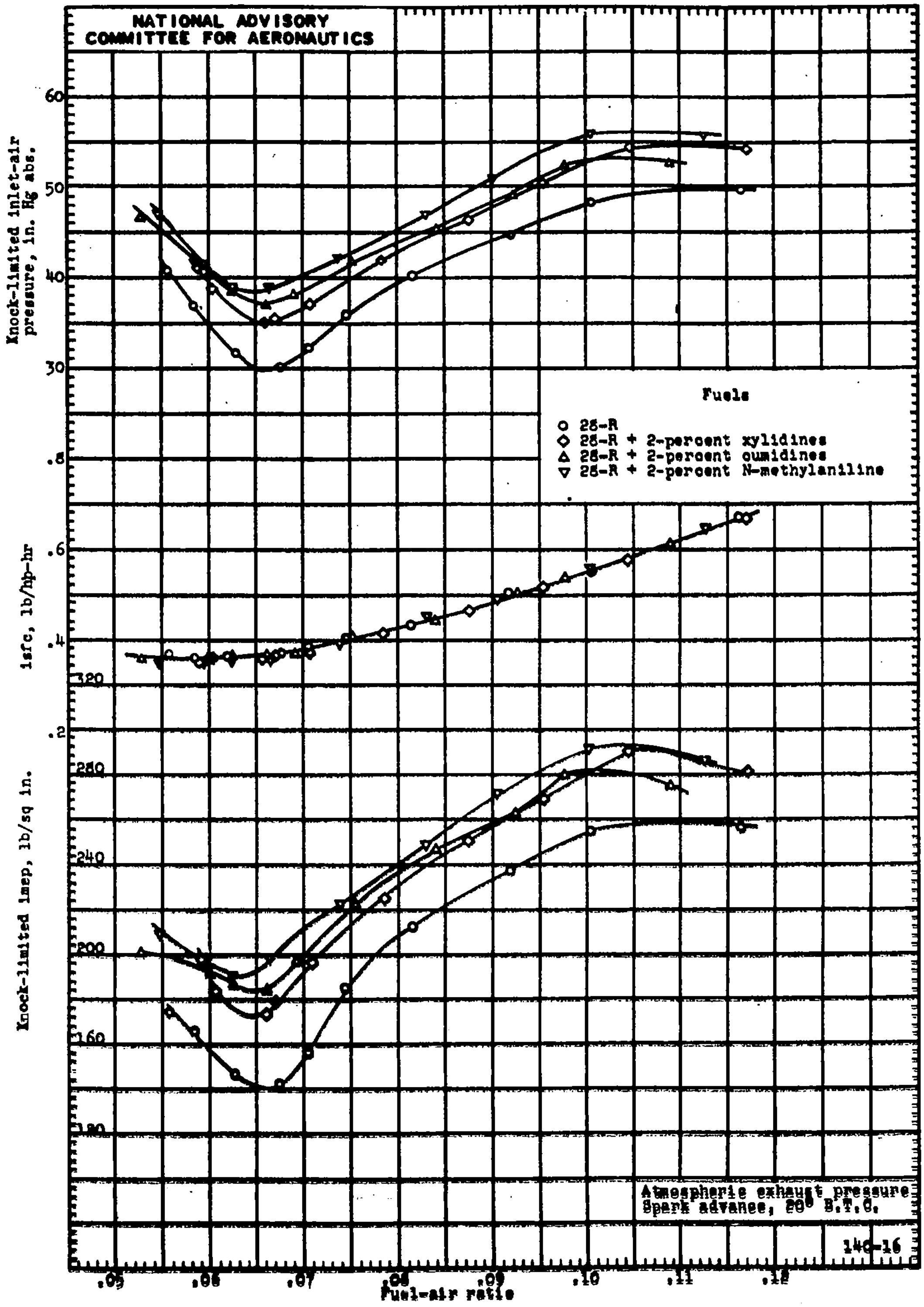


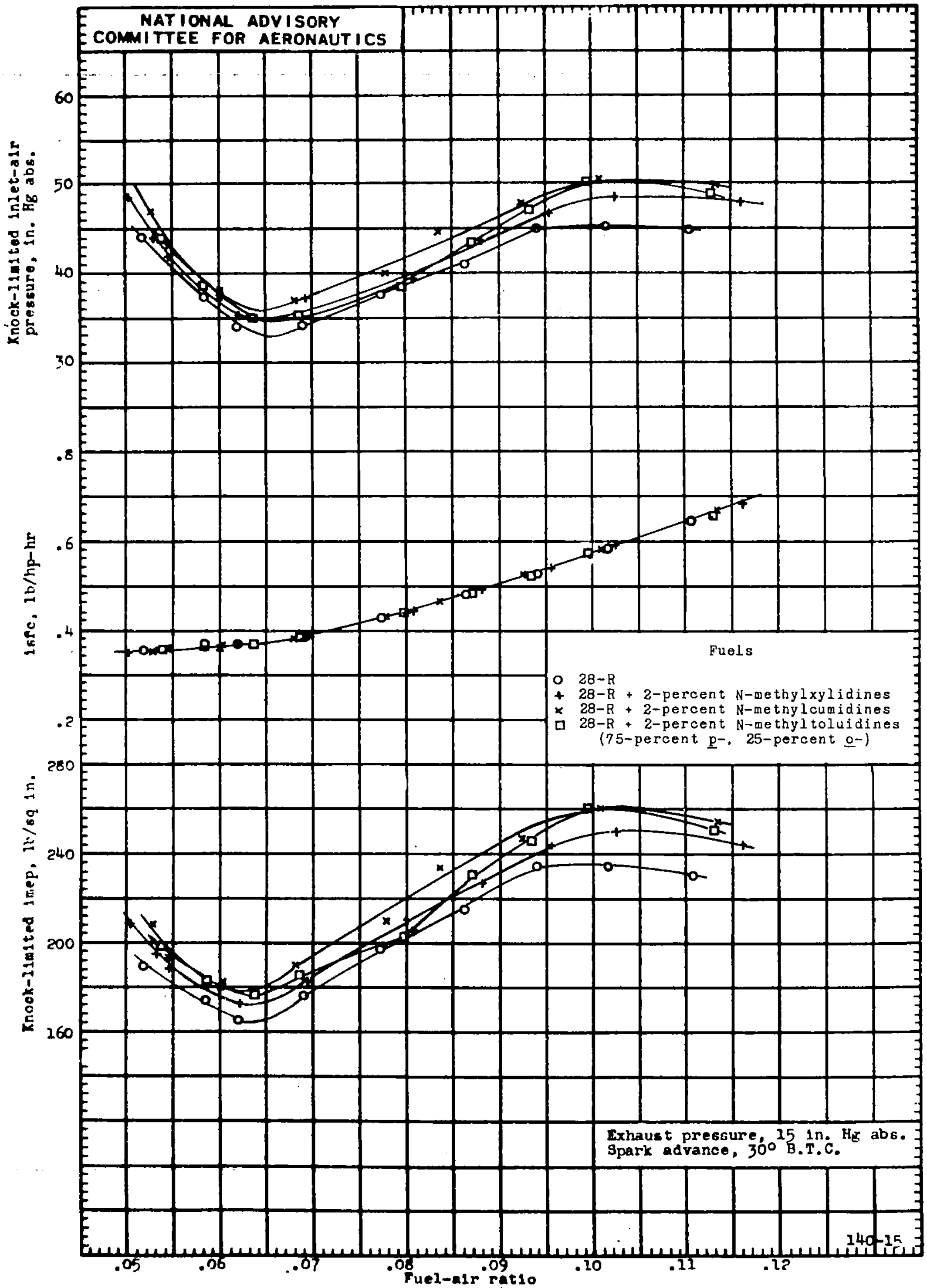

(a) Fuels, 28-R, N-methylxylidines, N-methylcumidines, and N-methyltoluidines (75-percent p-, 25-percent o-).

Figure 1. - Knock-limited performance of blends of 28-R fuel containing 2-percent aromatic amines at atmospheric exhaust pressure and a spark advance of 20° B.T.C. Wright R-1820 G200-cylinder; engine speed, 2000 rpm; inlet-air temperature, 210° F; compression ratio, 7.3; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F.



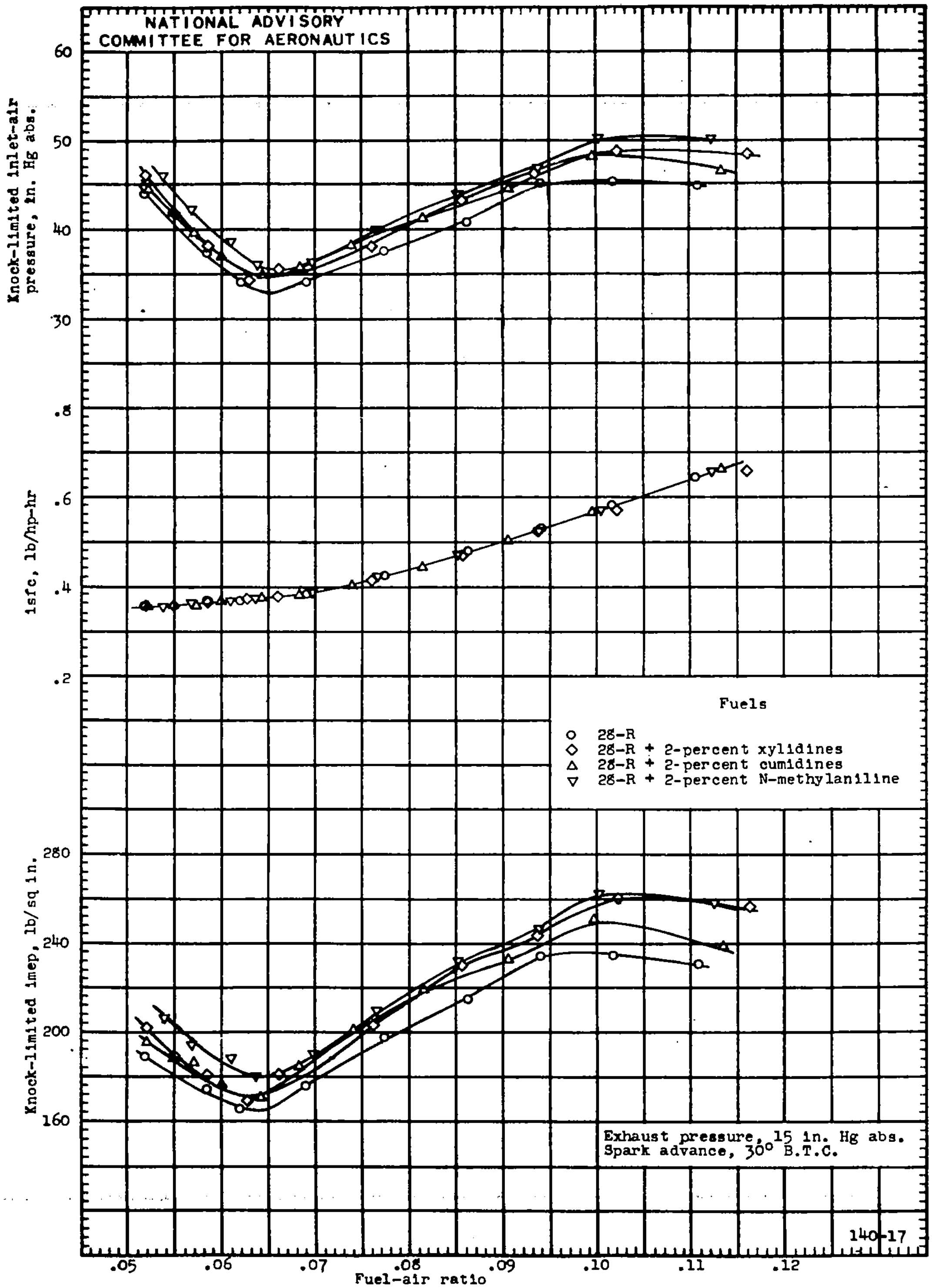

(b) Fuels, 28-R, xylidines, cumidines, and N-methylaniline.

Figure 1. - Concluded. Knock-limited performance of blends of 28-R fuel containing 2-percent aromatic amines at atmospheric exhaust pressure and a spark advance of 20° B.T.C. Wright R-1820 G200-cylinder; engine speed, 2000 rpm; inlet-air temperature, 210° F; compression ratio, 7.3; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F.




(a) Fuels, 28-R, N-methylxylidines, N-methylcumidines, and N-methyltoluidines (75-percent p-, 25-percent o-).

Figure 2. - Knock-limited performance of blends of 28-R fuel containing 2-percent aromatic amines at an exhaust pressure of 15 inches of mercury absolute and a spark advance of 30° B.T.C. Wright R-1820 G200 cylinder; engine speed, 2000 rpm; inlet-air temperature, 210° F; compression ratio, 7.3; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F.




(b) Fuels, 28-R, xylidines, cumidines, and N-methylaniline.

Figure 2. - Concluded. Knock-limited performance of blends of 28-R fuel containing 2-percent aromatic amines at an exhaust pressure of 15 inches of mercury absolute and a spark advance of 30° B.T.C. Wright R-1820 G200 cylinder; engine speed, 2000 rpm; inlet-air temperature, 210° F; compression ratio, 7.3; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F.

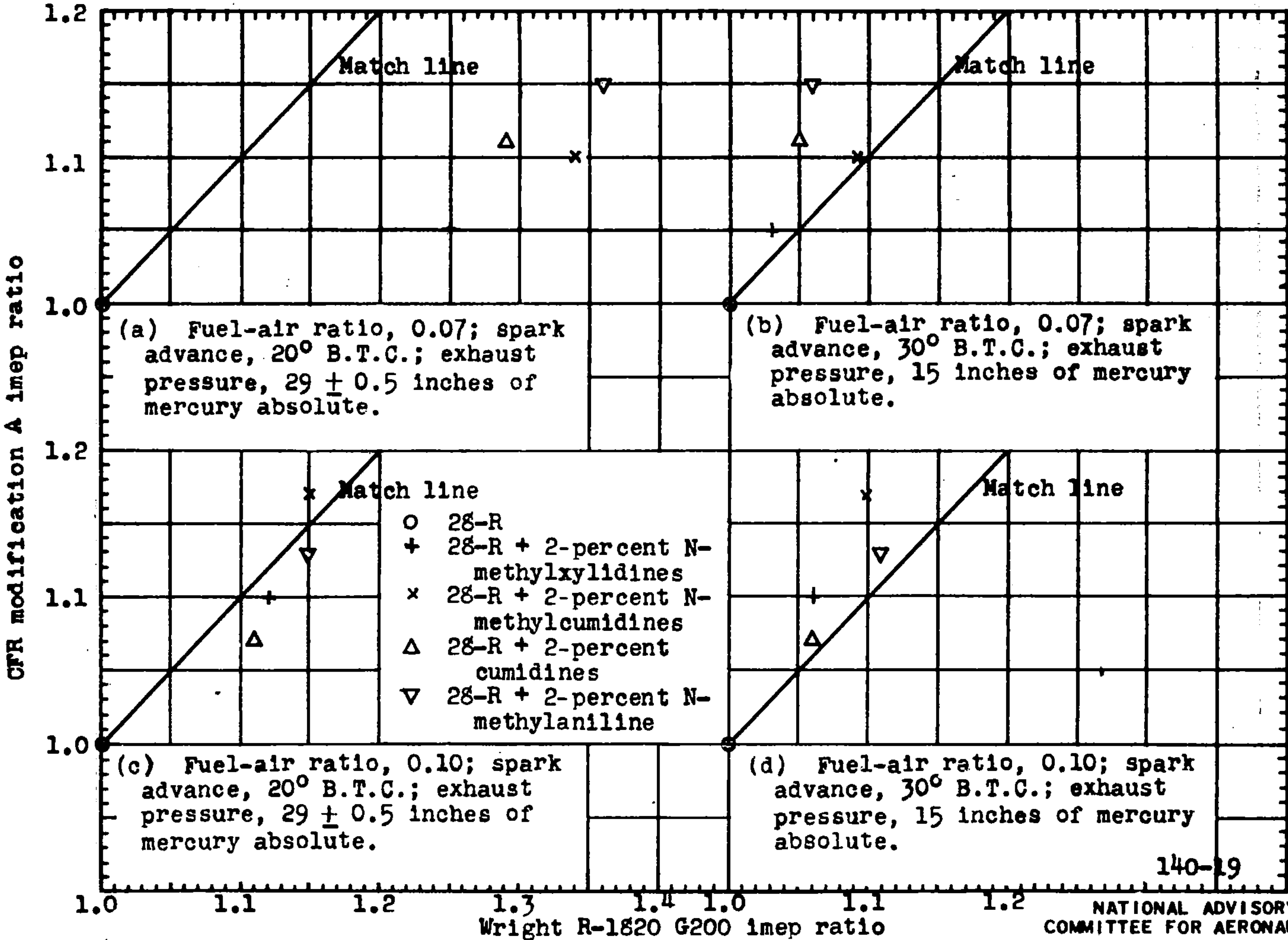



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Figure 4. - Correlation of Wright R-1820 G200 engine data with CFR modification A engine data. Wright R-1820 G200 conditions: engine speed, 2000 rpm; compression ratio, 7.3; inlet-air temperature, 210° F; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F. CFR modification A conditions: inlet-air temperature, 250° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

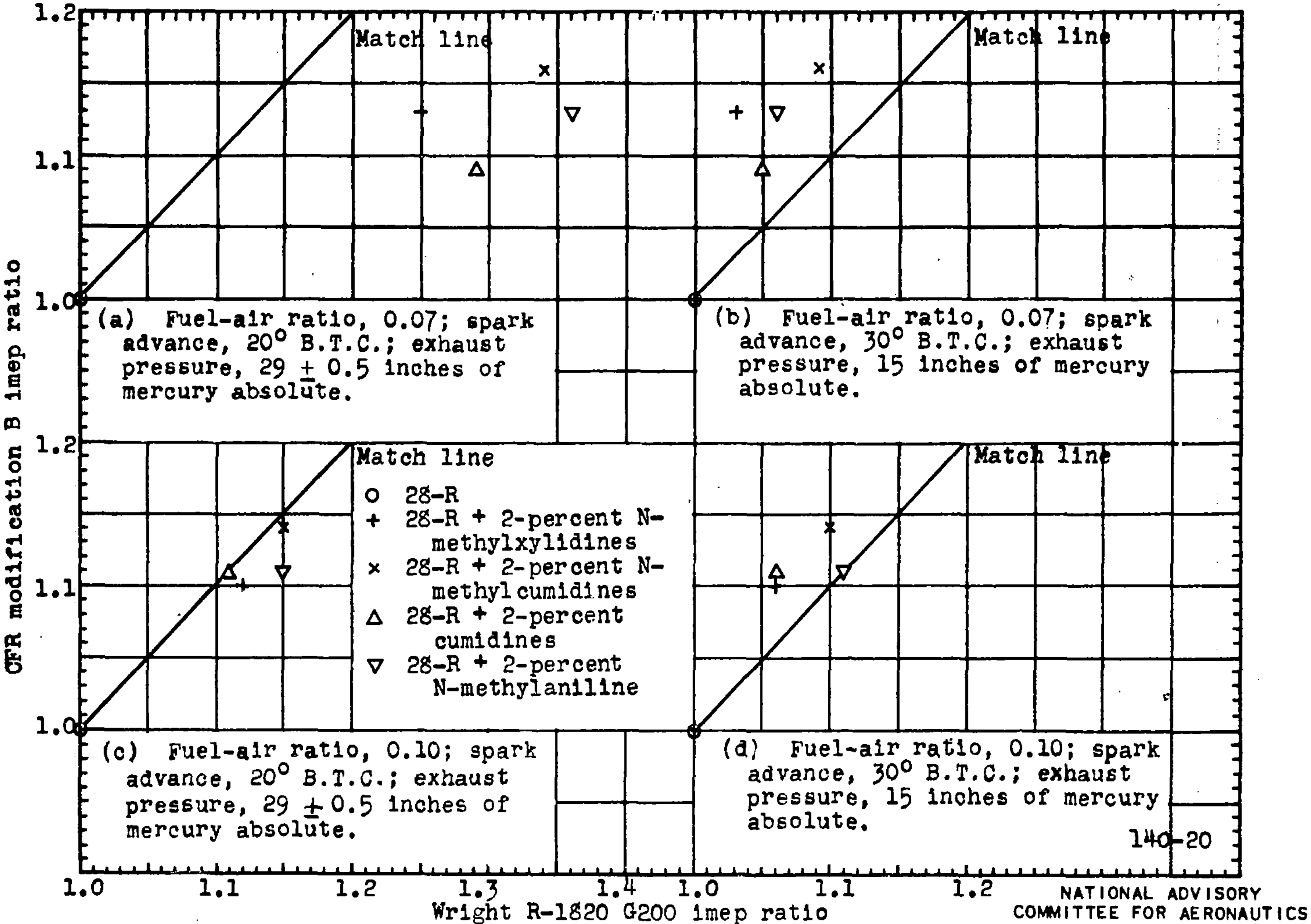


Figure 5. - Correlation of Wright R-1820 G200 engine data with CFR modification B engine data. Wright R-1820 G200 conditions: engine speed, 2000 rpm; compression ratio, 7.3; inlet-air temperature, 210° F; cooling air adjusted at 140 bmep and 0.10 fuel-air ratio to give a rear spark-plug-bushing temperature of 365° F. CFR modification B conditions: inlet-air temperature, 150° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.